# IGCC GREY WATER TREATMENT SYSTEM FOR DUKE ENERGY INDIANA'S EDWARDSPORT FACILITY IWC 10-48


Andrew Broerman
Process Engineer
Duke Energy
Edwardsport, IN

M. Adam Edwards
Process Designer
HPD, LLC
Plainfield, IL



## ABSTRACT

Duke Energy Indiana is constructing the first commercial-scale coal gasification plant built in the United States in the last 13 years in Edwardsport, Indiana. The plant will use advanced integrated gasification combined cycle (IGCC) technology to convert Indiana coal to a synthetic gas that is used to produce power. The process wastewater from gasification operations (grey water) must be treated to remove contaminants before it can be recycled to the plant or discharged to the environment. Environmental discharge requires exceptionally clean condensate and management of the various feed contaminants. This paper describes the development and design challenges of the Grey Water Treatment System.


## INTRODUCTION

Duke Energy is constructing the first large, commercial-scale coal gasification power plant built in the United States in Edwardsport, Indiana. The approximately 618-megawatt plant will use advanced integrated gasification combined cycle (IGCC) technology to convert Indiana coal to a synthetic gas (syngas) that is used to produce power. The syngas is cleaned to remove sulfur compounds, mercury, and particulate matter before being sent to a traditional combined cycle power plant, using two combustion turbines and a steam turbine to efficiently produce electricity. By-products of the gasification process include steam, vitrified slag and elemental sulfur.

Water is used in the cleanup of both the syngas and slag, most of which is recycled to the gasification process. This process wastewater from gasification operations is called grey water after the solids have been removed. The grey water is recycled back into the plant for re-use. However, a purge stream must be removed from the process to control the concentration of chloride, which is present in the coal feedstock. This purge stream is the feed stream to the Grey Water Treatment System

Based on permitting restrictions, the Edwardsport facility required that the treated water recovered from the Grey Water Treatment System be suitable for discharge. However, the discharge may be recycled to the cooling tower to reduce make up water rates. The processed water must meet stringent effluent quality specifications governed by the plant's NPDES permit. The suspended and dissolved solids separated by the Grey Water Treatment System are sent off-site for disposal.

## FEED CHEMISTRY AND DESIGN CHALLENGES

The grey water from the gasification process is to be treated to a degree that it may be discharged to the nearby river. This grey water contains ammonium, chloride, and formate ions as the primary contaminants. Other contaminants include mercury, selenium, boron, and arsenic, which are present in very low levels and require careful consideration given the final destination of the treated water.

Duke Energy required a system that would meet the following main objectives:

- Remove dissolved solids from the grey water
- Provide reliable and stable operation.
- Minimize operations and maintenance requirements
- Minimize overall CAPEX and OPEX requirements

Various treatment scenarios were considered, including ammonia stripping, softening, and biological treatments. Due to the highly buffered nature of the grey water, it was determined that converting the ammonium to ammonia for stripping would be prohibitively expensive. Biological treatment was considered risky due to the possibilities of inconsistent grey water production rate and composition.

Evaporation of the grey water was determined to be the approach that would satisfy the design goals. HPD LLC, a company in the family of Veolia Water Solutions and Technologies, was selected to provide the Grey Water Treatment System. Processing grey water via evaporation has been performed at other existing IGCC facilities, though in these cases the evaporator condensate is simply recycled back into the process, so some condensate contamination is considered acceptable. In the case of the Edwardsport facility, the condensate is being discharged to a river and therefore has much more stringent quality requirements.

When designing the system to meet these requirements, there are a number of challenges associated with condensate contamination due to the volatile nature of a number of the feed components including ammonia, formic acid, cyanic acid, and carbon dioxide. Each of these components also exhibit weak acid or base properties, suggesting that multi-stage processes and post-treatment would be required to separate the acids and bases.

## SYSTEM OVERVIEW

The Evaporation System was designed as a two-step evaporation / crystallization process followed by post-treatment of the condensate for further polishing. The first evaporation stage serves as a "pre-concentration" step, where the majority of the water is evaporated and very little crystallization occurs. The second evaporation stage is a patent-pending, low temperature process for the crystallization of the dissolved solids (primarily ammonium chloride).

In each of the evaporation stages a significant amount of ammonia is volatilized and condenses with the condensate. To remove ammonia from the condensate, a multi-stage, reverse osmosis (RO) system is used. This RO system utilizes a patented process for low pH operation to remove ammonia from the condensate. The RO System permeate is then run through a final oxidation step before being discharged to the river. **Figure 1** outlines the basic system.

The clarified grey water that is fed to treatment system does not undergo any further physical or chemical pretreatment. The equipment and chemical consumption associated with converting the feed from ammonium chloride chemistry to sodium chloride would result in high capital and operating costs. By dividing up the evaporation stages, and through strategic management of the various weak acids and bases, the system has been designed to minimize the power and chemical consumption requirements.

## PRE-CONCENTRATION STAGE

The first evaporation stage utilizes Mechanical Vapor Recompression (MVR) technology to evaporate 97% of the water. Due to the presence of calcium, aluminum, and silica in the feed, there will be precipitation in the first stage concentrator.

This is a common issue encountered in Cooling Tower Blowdown service. In most cases the pre-concentration step utilizes a falling film evaporator that has been "seeded" with calcium sulfate. The precipitating calcium sulfate is used to co-precipitate the aluminum and silica and minimize the scaling impact of these components. In some instances where the concentrations of silica relative to calcium are very high, calcium chloride is added to the feed to artificially increase the amount of precipitating calcium. The projected chemistry at Edwardsport contained very low levels of calcium hardness. The addition of calcium chloride would be cost prohibitive here, and falling film technology would be more prone to scaling. Additionally, seeding is somewhat risky with the grey water chemistry because of the presence of significant amounts of boron, metals and metalloids, and the low pH in the evaporator due to the presence of formic acid. All of these factors are known to adversely affect the seed slurry process.

Previous experience with operating IGCC plants also suggests that upsets in the upstream black water clarifiers can cause a significant amount of slag to carry over into the grey water to the evaporator. These upsets have often resulted in plugging of preheater equipment and evaporator tubes.

With these considerations in mind, the pre-concentration step was designed as a forced circulation evaporator rather than a falling film evaporator. Preheating was not included to eliminate fouling associated with this service, and due to the relatively high feed temperature. Forced circulation evaporators are less prone to scaling than falling film evaporators because evaporation occurs in a separate vapor body rather than on the tube surface. High recirculation velocities also help to minimize the supersaturation and tendency to fouling of the heat transfer surface. **Figure 2** is a simplified schematic of the Pre-Evaporation step.

During this evaporation step, the vapor contains a high concentration of volatile acids and ammonia. To remove the acids, a caustic scrubbing stage is utilized prior to compression of the vapors. The volatile acids are converted to the sodium salts of the respective conjugate bases and crystallized in a separate unit.

## CoLD™ CRYSTALLIZATION STAGE

The secondary evaporation stage crystallizes ammonium chloride and sulfate salts for landfill disposal. These salts are very soluble and exhibit normal solubility characteristics. The high solubility results in a high boiling point rise and therefore high operating temperature, which in turn drives up the solubility. The increased operating temperature limits the available heat sources to drive evaporation. The higher operating temperature and high chloride concentration also increases the corrosiveness of the circulating brine, requiring expensive exotic materials. **Figure 3** shows the solubility and boiling point of ammonium chloride at atmospheric conditions.

In order to manage these issues, the final crystallization stage occurs at low temperature. This **C**rystallization at **L**ow Temperature and **D**eep Vacuum (CoLD™) process decreases the solubility of these salts. This in turn allows the crystallizer to use low-pressure steam (15 psig) for heat integration. The low temperature also allows the final crystallizer to be built of reasonable materials of construction. The decreased solubility and boiling point under vacuum conditions is demonstrated in **Figure 4**.

Salts generated in the CoLD crystallizer are dewatered using a pressure filter. The resulting wetcake will then be landfilled. As with the pre-concentration step, the vapors produced in the evaporation process are scrubbed with caustic to remove volatile acids. A simplified diagram of the system is presented in **Figure 5**.

## CONDENSATE POLISHING

The condensates from the various evaporation operations are combined and processed through a Reverse Osmosis system for ammonia removal. Under typical operating conditions for a wastewater RO, ammonia is not ionized and therefore not rejected by the membrane. The Duke Energy polishing system utilizes a double pass RO system with the first pass operated under acidic conditions and the second pass at slightly acidic pH conditions. The RO system membranes are designed by system designer and Dow for operation at low pH.

When the pH of the condensate is less than approximately 5.4, virtually all of the ammonia is ionized as ammonium. The ammonium is then rejected by the RO system as ammonium sulfate (with the sulfate coming from the addition of sulfuric acid to decrease the pH). This reject stream is re-processed through the evaporation system and ultimately rejected from the system as ammonium sulfate. The RO will achieve greater than 90% water recovery and 99% removal of ammonia.

The RO system permeate is oxidized at high pH with sodium hypochlorite to remove residual cyanide, formate, and other contaminants. This stream is then neutralized with sodium bisulfate and acid before being discharged.

## CONCLUSION

The Grey Water Treatment System for Duke Energy's Edwardsport facility is a state-of-the-art design that will allow produced condensate clean enough to be discharged to the environment. The system incorporates lessons learned from the first generation, demonstration IGCC plants—and from other industries—to minimize operational difficulties and costs.

# Referenced Figures

**Figure 1: Grey Water Treatment System Block Diagram**

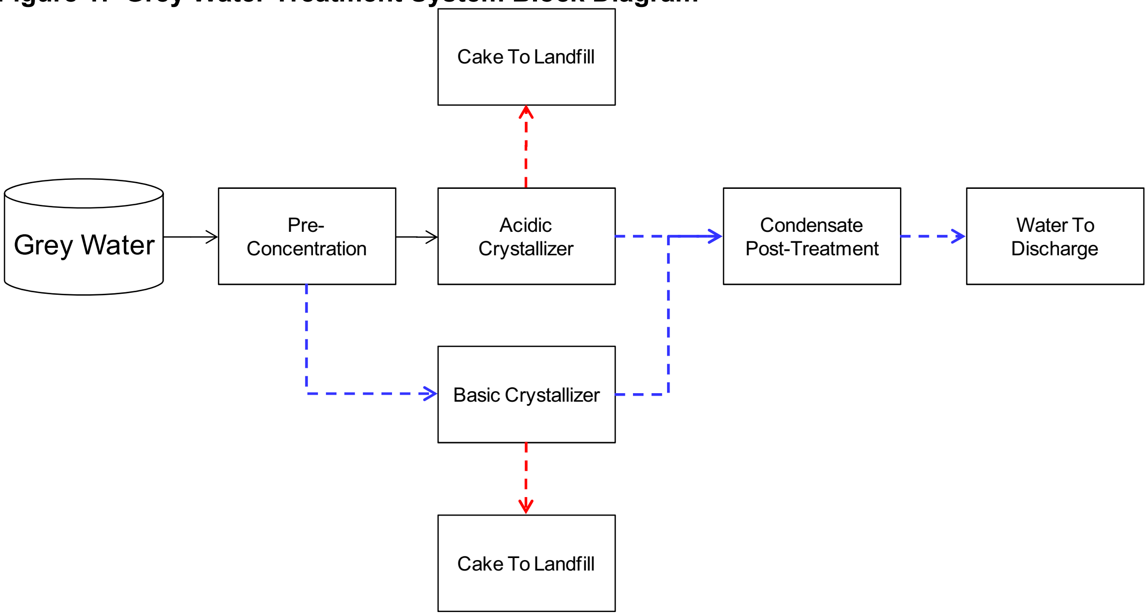



**Figure 2: Forced Circulation Pre-Concentration Stage With Integral Vapor Scrubbing**

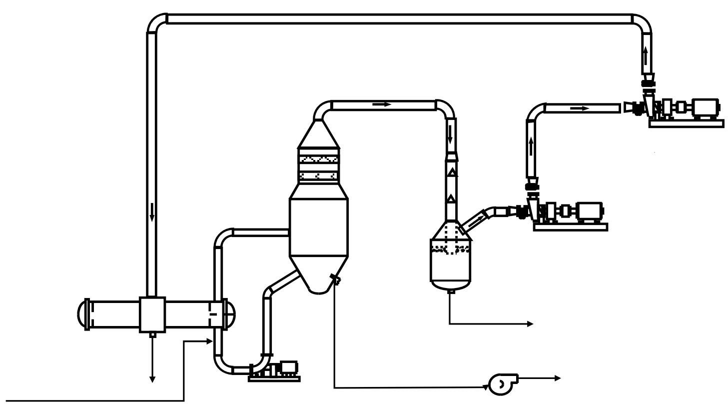


**Figure 3: Ammonium Chloride - Solubility and BP At Atmospheric Conditions**

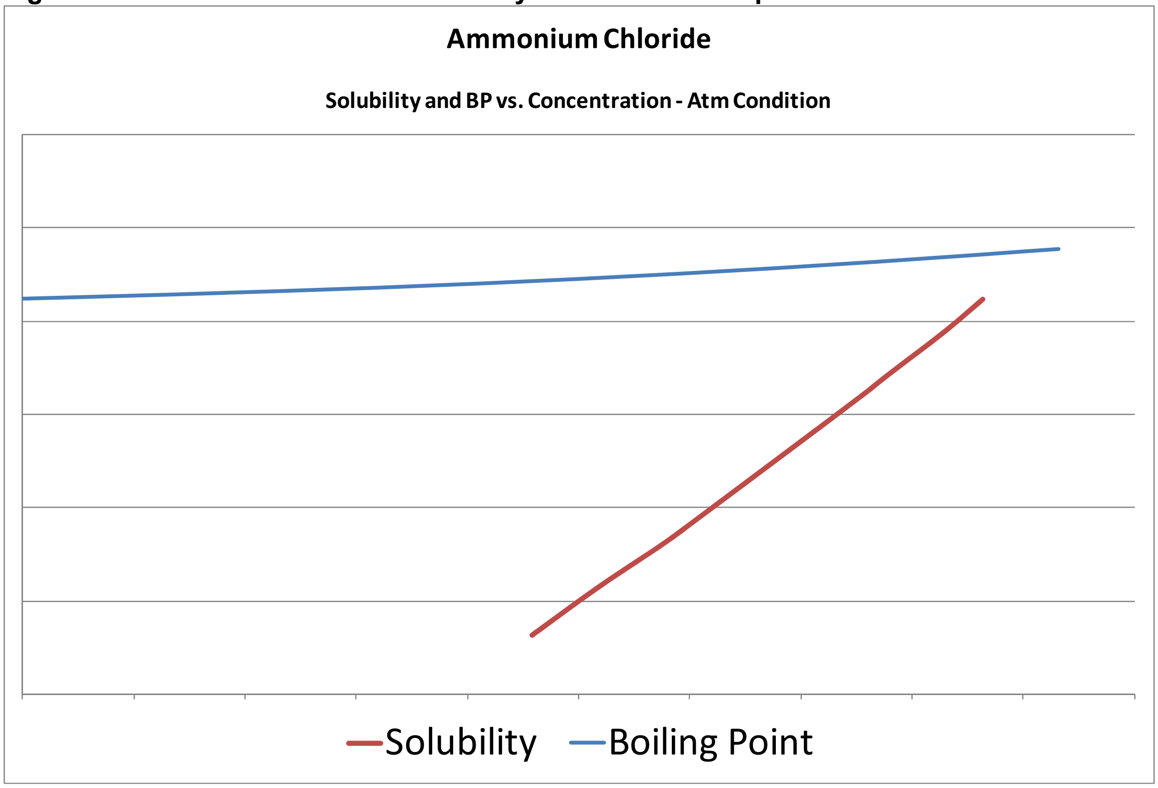
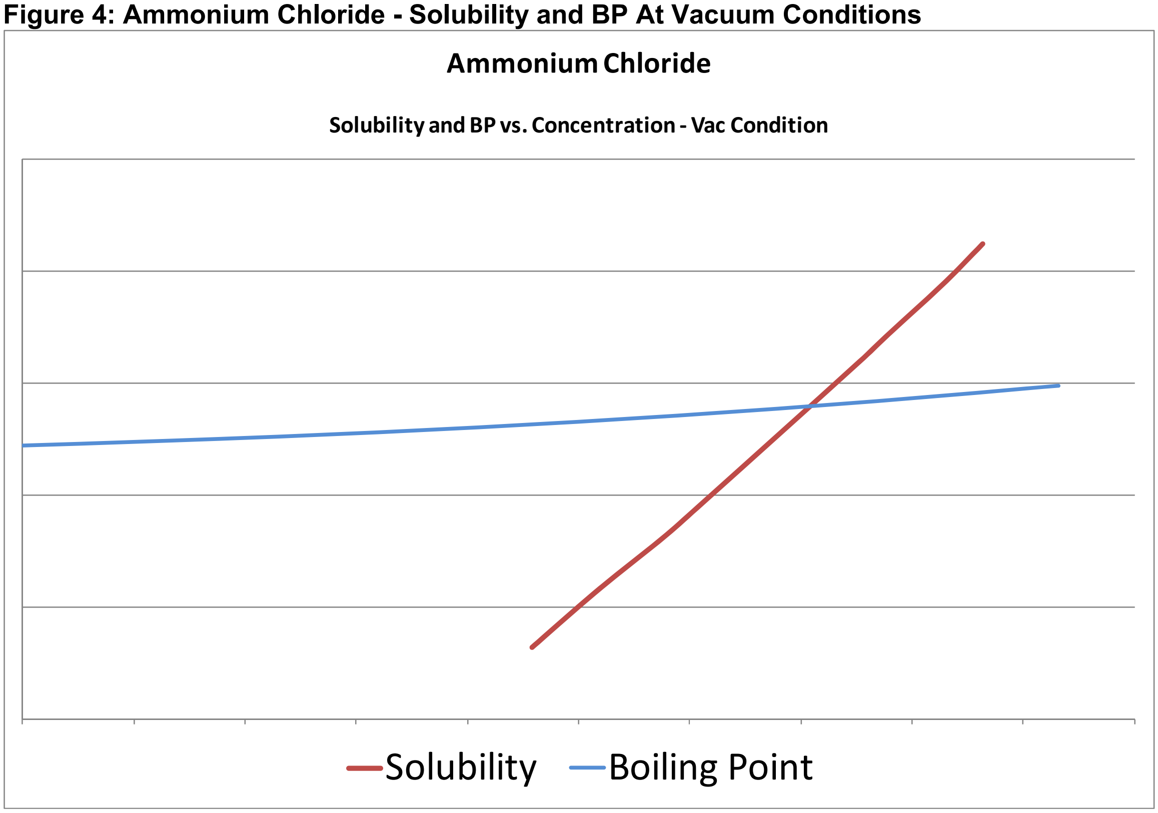



**Figure 4: Ammonium Chloride - Solubility and BP At Vacuum Conditions**



## Figure 5: CoLD Crystallizer System